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EFFECTS OF LONGTIME ENVIRONMENTAL EXPOSURE ON MECHANICAL PROPERTIES OF SHEET MATERIALS FOR A SUPERSONIC TRANSPORT

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EFFECTS OF LONGTIME ENVIRONMENTAL EXPOSURE ON MECHANICAL PROPERTIES OF SHEET MATERIALS FOR A SUPERSONIC TRANSPORT*

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SUMMARY

Studies of the effects of longtime environmental exposure on mechanical properties of supersonic transport sheet materials have been conducted by the Langley Research Center. These materials include titanium alloys, stainless steels, aluminum alloys, and a composite. Titanium alloys and stainless steels have been investigated since 1961, and results have shown that exposures of 30 000 hours at 550° F (561° K) have had little effect on the strength characteristics. Hot-salt stress corrosion occurs in titanium alloys under certain combinations of stress, temperature, and time but does not appear to be a problem at the operating conditions of a Mach 2.7 supersonic transport. Aluminum alloys were investigated to provide materials information for the Mach 2 speed range and have been found to be temperature limited by longtime creep strength. Properties of the polyimide-resin—glass-fiber composite have been determined after 4000 hours exposure. This material appears to be suitable for extended use in a Mach 2.7 supersonic transport.

INTRODUCTION

Significant materials research in support of the commercial supersonic transport began about 1960 when the speed and other operating characteristics of the transport were tentatively defined. Since then, materials investigations have been initiated in many diverse areas. The materials research program at the Langley Research Center has been concerned primarily with the effects of longtime environmental exposure on the mechanical properties of various sheet materials: titanium alloys, stainless steels, aluminum alloys, and a composite (refs. 1 to 5). The present paper summarizes some of the more significant results of this program.

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Research on titanium alloys and stainless steels began in 1961 in response to a Mach 3 design requirement. Environmental exposures on some of these materials now exceed 30 000 hours. Several investigations on aluminum alloys were begun in 1963 to provide materials information for the Mach 2 speed range, and environmental exposure times are now up to 22 000 hours. Composite materials are being used increasingly in subsonic transports in areas where weight can be saved both as glass-fiber and epoxy-resin composites and as adhesively bonded metal composites. There is reason to believe that composite materials will also be used in the supersonic transport if available polymeric-resin systems will retain adequate mechanical properties after long exposures in the high temperature supersonic environment. One such composite material, a polyimide-resin—glass-fiber laminate, has been under study since 1965 and may be used in large areas of secondary structure on the currently proposed Mach 2.7 transport.

The units used for physical quantities defined in this paper are given both in the U.S. Customary Units and in the International System of Units (SI). Conversion factors pertinent to the present investigation are presented in the appendix and in reference 6.

MATERIALS AND TESTS

Materials

Materials included in this research program were considered, at the time each of the several studies was initiated, to be among the more promising materials for supersonic transport application or to be representative of an important class of material. Table I gives the alloys selected, heat-treated condition, and nominal thickness.

Details of heat treatment for all the titanium alloys and stainless steels are given in reference 1 except for the Ti-8Al-1Mo-1V duplex annealed. Duplex annealed material is first mill annealed and then heated to 1450° F (1060° K), held for 15 minutes, and air cooled. Aluminum clad 2024-T81 alloy sheet is solution heat treated at 920° F (770° K), water quenched, cold worked, and precipitation heat treated at 375° F (464° K) between 11 and 13 hours. The clad RR-58 is a high-temperature British alloy considered for supersonic transport applications. This alloy is solution heat treated 1 hour between 977° and 995° F (800° and 810° K), water quenched, and aged 20 hours at 390° F (470° K).

The composite material was laminated from multiple plies of E glass fabric (181 style) preimpregnated with polyimide resin. Lamination was accomplished by a vacuum bag process which included a cure cycle of 1.5 hours at 350° F (450° K) followed by several postcures which terminated with 8 hours in air at 600° F (589° K). Details of this process are given in reference 5. The post-cured material consisted of the following partial volumes: glass, 48 to 51 percent; polyimide resin, 26 to 28 percent; and voids, 23 to 24 percent.

TABLE I.- HEAT-TREATMENT DESIGNATIONS AND SHEET THICKNESS OF MATERIALS INVESTIGATED

Material	Heat-treated condition	Nominal thickness, in. (cm)
Titanium alloys:		
Ti-6Al-4V	Annealed (AN)	0.040 (0.102)
Ti-4Al-3Mo-1V	Solution treated and aged (STA)	0.040 (0.102)
Ti-13V-11Cr-3Al	Single aged (SA)	0.040 (0.102)
Ti-8Al-1Mo-1V	Mill annealed (MA)	0.040 (0.102)
Ti-8Al-1Mo-1V	Duplex annealed (DA)	0.050 (0.127)
		0.065 (0.165)
Stainless steels:		
AISI 301	Cold rolled (CR)	0.025 (0.064)
PH 15-7 Mo	Transformation and precipitation hardened (TH 1050)	0.025 (0.064)
PH 14-8 Mo	Subzero transformation and precipitation hardened (SRH 950)	0.050 (0.127)
AM-350	Cold rolled and tempered (CRT)	0.025 (0.064)
AM-350	Double aged (DA)	0.025 (0.064)
Aluminum alloys:		
Clad 2024	Solution treated and aged (T81)	0.064 (0.163)
Clad RR-58	Solution treated and aged	0.064 (0.163)
Composite material:		
Polyimide resin glass fiber		0.037 (0.094)
		0.125 (0.318)

Test Specimens and Procedures

The various types of specimens used in obtaining the data in this investigation are shown in figure 1. In general, quantities of each of these types of specimens were placed in various furnaces and exposed to air at temperatures ranging from 250° to 600° F (395° to 589° K). Periodically, small numbers of specimens were removed and tested at room temperature to determine effects of the exposure.

The standard tensile specimen (fig. 1(a)) is used in studies to determine the effect of longtime environmental exposures on the room-temperature tensile strength of titanium alloys, stainless steels, and aluminum alloys. Tensile tests were conducted under controlled strain-rate conditions of approximately 0.001 per minute elastically which is increased to 0.005 per minute in the vicinity of the yield; this rate is then further increased beyond yield to 0.05 per minute which is maintained until fracture occurs.

Specimens with the same reduced section but of greater over-all length and width are used in studies to determine the effect of higher strain rates and in studies of creep strength of the aluminum alloys. Creep tests are performed in deadweight loading machines equipped with tube furnaces which heat the test section of the specimen uniformly to the prescribed temperatures. Creep strain is determined by periodically removing the specimen from the furnace and measuring the permanent extension at room temperature with an optical micrometer.

The sharp V-notch specimen (fig. 1(a)) has edge notches finished to a base radius between approximately 0.0005 and 0.0007 inch (13 and 18 μm) which corresponds to an elastic stress concentration factor of about 20. Notch specimen testing in tension is performed at a constant net-section stress rate corresponding to an elastic strain rate of about 0.001 per minute. Both the standard tensile specimen and the sharp V-notch specimen conform to the specifications and recommendations of the American Society for Testing and Materials (ASTM).

The self-stressed corrosion specimen (fig. 1(a)) is formed by bending the ends of two strips of material, then clamping and spotwelding the ends together to bow the two strips as indicated. The magnitude of the bending stresses in each strip is related to the center deflection from the longitudinal axis. Additional details for construction and cleaning are given in references 2 and 3. Testing is done by restraining the ends of the specimen in fixtures and compression loading as a fixed-end column. As the load increases, the individual strips bend more and the specimen shortens. Failure occurs by cracking in the region of maximum bending curvature. The magnitude of compressive shortening at failure is an indicator of the residual ductility in the self-stressed specimen.

The spot-weld specimen (fig. 1(a)) is the cross-tension type in which the single spot-weld holding the two pieces of sheet together is loaded in tension with a pin fixture pushing through the holes.

In order to study the influence of various fabrication methods on the behavior of a typical aircraft structural component, the skin-stringer panel shown in figure 1(b) was designed and fabricated from Ti-8Al-1Mo-1V duplex annealed sheet. The stringers were attached to the skin by various methods including riveting, resistance spot-welding, arc spot-welding, tungsten-inert-gas (TIG) fusion welding, and diffusion bonding. Ends of the panels were machined flat for compression loading. Panel proportions were selected to insure that local buckling would occur in the skin between stringers and in the webs and flanges of the stringers at stresses well below the crippling failure stresses. Thus, the integrity of the various types of joints could be investigated as they were bent and twisted by the buckling deformations.

Compression tests of the panels were conducted at room temperature and at elevated temperatures. A quartz-lamp radiator installed between the testing machine

loading heads heated the panels from the skin side only so that, at a steady-state skin temperature of 600° F (589° K), the average temperatures in the stringer flanges and webs were as shown in figure 1(b).

Test specimens used in the polyimide-resin—glass-fiber composite material study include beams of two lengths and the honeycomb core sandwich with laminated faces. The beams were cut from 13-ply laminated material and loaded transversely in the center with the ends simply supported. The longer beam was used in tests to determine bending failure stresses and the shorter beam, to determine shear failure (interlaminar shear) stresses. Both the core and the faces of the honeycomb core sandwich were made from glass-fiber fabric and the polyimide resin. Extra resin was used to bond adhesively the faces to the core. Tests performed on the sandwich include edgewise compression, flatwise tension tending to pull the faces off the core, and shear of the core.

RESULTS AND DISCUSSION

Titanium Alloys

Tensile strength.- The effect of longtime exposure at 550° F (561° K) on the room-temperature tensile strength of the five titanium alloys investigated is shown in figure 2. Relative strength – that is, the strength after exposure divided by the strength before exposure – is plotted for exposure times up to 30 000 hours. Note that the relative strength scale is greatly enlarged and contains values only between 0.8 and 1.2. No significant change in tensile strength has occurred for any of the alloys shown. The 550° F (561° K) exposure temperature was selected to correspond to a Mach 3 design condition.

Notch strength.- The effect of a similar exposure at 550° F (561° K) on the notch tensile strength of the same five titanium alloys is shown in figure 3. No significant degradation has occurred for either the Ti-6Al-4V or the Ti-4Al-3Mo-1V alloy. About a 10-percent reduction in notch strength has occurred in the Ti-8Al-1Mo-1V alloys after 22 000 hours for the mill annealed material and after only 2000 hours for the duplex annealed material. Reductions up to about 18 percent have occurred in the Ti-13V-11Cr-3Al alloy.

Strain-rate sensitivity.- Since standard laboratory testing speeds are quite slow compared to aircraft loading rates, the response of several titanium alloys to various strain rates has been investigated. The data shown in figures 4 and 5 are some of the unpublished results from an investigation conducted at the Langley Research Center, which is an extension of work reported in reference 1. Figure 4 presents the strain-rate sensitivity for Ti-8Al-1Mo-1V alloy in the mill annealed condition. The absolute tensile strength rather than the relative strength is shown after various exposure times and for three strain rates. The lowest curve corresponds to standard laboratory testing speeds

and was used in plotting the curve for this material in figure 2. At this strain rate about 5 minutes are required to load to failure. The top curve (fig. 4) represents strengths obtained in tests lasting only a fraction of a second and indicates about a 10-percent increase in tensile strength. This spread in tensile strength remains essentially constant for exposures to 550° F (561° K) from 0 to 22 000 hours.

The corresponding strain-rate sensitivity of notch tensile strength for Ti-8Al-1Mo-1V (MA) alloy is shown in figure 5. The lowest curve again corresponds to standard laboratory testing speeds. A considerably larger increase in notch strength is obtained by testing at the higher strain rates, and the notch strength response to the three strain rates remains essentially unchanged by the 550° F (561° K) exposure up to 22 000 hours. In addition, at the higher strain rates the detrimental effect of the sharp notches on strength diminishes. At the strain rate of 5 per second, the notch-to-tensile strength ratio approaches unity.

Stress corrosion.- The supersonic transport will be operating from a number of airports along seacoasts, and the possibility exists of salt deposits forming on various parts of the airframe. An investigation of hot-salt stress corrosion for several titanium alloys has been conducted at the Langley Research Center (ref. 2). Ti-8Al-1Mo-1V duplex annealed sheet has been studied extensively (see, for example, ref. 3), and the results are summarized in figure 6 for 10 000 hours exposure at stresses up to 60 ksi (410 MN/m^2) and at temperatures from 400° F to 600° F (477° K to 589° K). The curve drawn through the data indicates the boundary conditions for the initiation of stress corrosion cracking in 10 000 hours. The solid data points above the curve represent specimens in which stress corrosion cracks were found. The specimens for points below the curve showed no corrosion cracking. Stress corrosion cracking can be initiated at temperatures between 400° F and 450° F (477° K and 505° K) if the stresses are between 50 and 60 ksi (345 and 410 MN/m^2); however, if the stress is kept below 25 ksi (170 MN/m^2), cracking will not occur at temperatures less than 550° F (561° K). Reference 2 indicates that Ti-8Al-1Mo-1V alloy is among the most severely affected of the titanium alloys. Therefore, on the basis of these data, hot-salt stress corrosion cracking of titanium alloys would not be expected to be a problem for the Mach 2.7 supersonic transport airframe with operating stresses below 25 ksi (170 MN/m^2) and operating temperatures below 450° F (505° K).

If the supersonic transport speed is increased, corrosion protection may be required because of the increase in cruising temperatures. An indication of the effectiveness of various protective treatments for duplex annealed Ti-8Al-1Mo-1V coated with salt and exposed at 600° F (589° K) is shown in figure 7. With no protection a high percentage of corrosion damage is indicated in relatively short times. The term "corrosion damage" as used herein indicates the severity of corrosion cracking as determined by a function of the relative shortening of the self-stressed corrosion specimen (fig. 1(a))

before and after environmental exposure. All treatments afforded good protection for 10 000 hours in still air except for the polyimide coating which started to crack and spall off the surface after 1000 hours exposure. These results, taken from reference 4, indicate that hot-salt stress corrosion can be alleviated or controlled to considerable extent by various surface treatments.

Fabrication.- The fabrication of titanium alloys into structural components requires joining. Spot-welding is one method of joining which can be performed easily in titanium alloys. Figure 8 shows results of exposures at 550° F (561° K) for times up to 22 000 hours on the tensile strength of spot-welds. In contrast to the tensile and notch strength results presented previously, these results show that the tensile spot-weld strength decreased significantly for three of the titanium alloys after exposure. All spot-welds were made on as-received sheet with no postweld heat treatments. A disturbing factor from the standpoint of various heat treatments on the same alloy is indicated by the increase in spot-weld strength of the 8Al-1Mo-1V duplex annealed alloy after exposure. The same alloy in the mill annealed condition experienced a decrease in spot-weld strength. However, these effects may not be as severe at the 450° F (505° K) operating temperature for Mach 2.7 at comparable exposure times.

In addition to spot-welding, titanium alloys can be fabricated into structural members by a variety of other joining techniques. Figure 9 shows the compressive strength of skin-stringer panels constructed from Ti-8Al-1Mo-1V (DA) alloy by the fabrication methods indicated. Test strengths at room temperature, shown by the dotted bars, are generally comparable. Similarly, test strengths at elevated temperature, shown by the hatched bars, are generally comparable for the various joining methods but are about 80 percent of the strength at room temperature. This reduction in panel strength at elevated temperature corresponds to the reduction calculated by a maximum strength theory (ref. 7). The calculated panel strength is based on an area-weighted average of the strengths of individual panel elements which, in turn, are functions of the material properties at average element temperatures (fig. 1(b)). In the same manner as was indicated in reference 7, the thermal stresses which influence the magnitude of the buckling load are largely alleviated in the interval between buckling and maximum load and do not appear to have affected the panel failure.

Results for a set of similar panels of Ti-8Al-1Mo-1V duplex annealed material which were exposed at 600° F (589° K) for 1000 hours with a salt coating and then were compression tested at room temperature are given in figure 10. The strengths after exposure (hatched bars) are compared with the as-fabricated test strengths (dotted bars) from figure 9. No significant change in strength occurred although after failure several panels exhibited more longitudinal cracking in the stringer bend radii than did unexposed panels. Generally, it has been found that in all types of hot-salt corrosion cracking tests, the effects are much more pronounced on the ductility than on the strength of the

specimen. For the diffusion bonded panel tests, two sets of panels were exposed at temperature; one with a salt coating and one without. Neither the salt nor the exposure seemed to have any effect on the room-temperature strength.

Stainless Steels

Tensile strength.- The effect of unstressed exposure to 550° F (561° K) for up to 30 000 hours on the tensile strength of five stainless steels is shown in figure 11. Four of the materials show no significant change in strength. The AISI 301 steel shows an increase in tensile strength of about 13 percent. However, the corresponding elongation dropped from 6 percent to 3 percent.

Notch strength.- Figure 12 shows a similar comparison of notch strengths for the five stainless steels. After unstressed exposure to 550° F (561° K) up to 30 000 hours, no significant degradation has occurred in the notch strength of the stainless steels. Again, the AISI 301 steel shows an increase in notch strength of about 10 percent with exposure, but the strengths of the other steels changed less than 5 percent.

Aluminum Alloys

Tensile and notch strength.- Tensile and notch strength data for two aluminum alloys, 2024-T81 and RR-58, are presented in figure 13. After unstressed exposure to 300° F (422° K) up to 22 000 hours, both the tensile strength and notch strength of the two aluminum alloys decreased about 10 percent. Since aluminum is being used nearer its limiting temperature, creep is potentially more of a problem than tensile strength.

Creep.- Figure 14 shows the stresses required to produce 0.1-percent creep strain in the two aluminum alloys over a range of temperatures and times. The RR-58 alloy is slightly less creep resistant than the 2024-T81 alloy. Both alloys show a rather severe reduction in allowable creep strength for temperatures greater than 250° F (395° K) at exposure times of 10 000 hours or more.

Polyimide-Resin—Glass-Fiber Composite

Compressive stiffness.- Figure 15 shows the effect of various exposures on the edgewise compressive stiffness of honeycomb core sandwiches. The effect is shown in terms of the ratio of the compressive modulus after environmental exposure to the modulus prior to exposure. The 450° F (505° K) exposures represent the operating temperature for the currently proposed Mach 2.7 design condition; the 600° F (589° K) exposures are all accelerated tests to study the degradation mechanism. The 35-torr (5 kN/m^2) condition is the pressure at an altitude of 60 000 feet (18.3 km), and the cyclic exposures are 2-hour cycles of both temperature and pressure to simulate a typical flight. No significant degradation is noted in any of the exposure environments for times approaching

1000 hours. The considerable degradation after 1000 hours at 600° F (589° K) does not preclude the use of polyimide-resin—glass-fiber sandwich construction in the Mach 2.7 supersonic transport. The degradation appears to be associated with oxidation of the polyimide resin which is accelerated considerably at the 600° F (589° K) exposure temperature. The 450° F (505° K) curve indicates no change in compressive modulus for times up to 4000 hours.

Compressive strength.- The corresponding exposure data for compressive strength of honeycomb core sandwiches are shown in figure 16. Effects of the various exposures on the room-temperature compressive strength are more pronounced than they were on modulus. During exposures at 600° F (589° K) at sea-level pressure, the strength decreases rapidly and continues to decrease until complete degradation has occurred after 2000 hours. Exposures at 35-torr (5 kN/m^2) degraded the compressive strength about one-half as much as did exposures at the higher pressures for similar exposure times. At 450° F (505° K), exposures up to 4000 hours have had only a slight effect on compressive strength.

Comparison of sandwich and beam specimens.- Behavior similar to that noted in the sandwich compression tests has been obtained in tests of sandwiches in shear and flatwise tension and in tests of laminated beams in bending and shear. Sandwich specimens are more representative of the airframe construction, but they are more expensive to fabricate and more difficult to test than the laminated beams. Therefore, it is of interest to establish a comparison of behavior in sandwiches and beams.

Figure 17 shows one such comparison for exposures at 450° and 600° F (505° and 589° K) at sea-level pressure. The solid curves represent the flatwise tensile strength ratio for sandwiches, and the dashed curves represent the flexure strength ratio for beams. The effects are quite comparable. Similar comparisons have been made between tests of sandwiches in shear and edge compression and tests of laminated beams in shear. It therefore appears that the simple beam test is sufficient to measure the degradation in strength and stiffness of the more complex sandwich.

Strength correlation.- A strength correlation of the effects of both 450° and 600° F (505° and 589° K) exposures for the polyimide-resin—glass-fiber sandwiches is shown in figure 18. The correlation is based on a Larson-Miller parameter plot (ref. 8) in which T_K is the exposure temperature in degrees Kelvin, t is the exposure time, and C is a constant which is empirically adjusted to make the data for both temperatures fall on the same curve. By using the values of C noted for the double shear, flatwise tension, and edge compression data, the three types of test data appear to aline quite well over the range of exposure times from 50 to 4000 hours. The circles and squares represent, respectively, the 600° F (589° K) data and the 450° F (505° K) data. The vertical lines through the symbols indicate the scatter in test results. It is not known the amount of

strength degradation that will be permitted in the final supersonic transport design. If a 50-percent degradation of strength is arbitrarily selected as the criterion for service life, then a service life between 30 000 and 60 000 hours at the 450° F (505° K) operating temperature is predicted on the basis of these preliminary data, as indicated by the short horizontal bars.

CONCLUSIONS

Some of the more significant results of several investigations concerned with the effects of longtime environmental exposure on the behavior of sheet materials have been presented. The environments have generally been selected to simulate operating conditions for proposed commercial supersonic transports. The following conclusions are drawn from the results:

1. Exposures for 30 000 hours at 550° F (561° K) have had little effect on the strength characteristics for most of the titanium alloys investigated.

2. Hot-salt stress corrosion in titanium alloys occurs under various combinations of stress, temperature, and time but does not appear to be a problem for the operating conditions of a Mach 2.7 supersonic transport.

3. Fabrication studies have shown that titanium alloys can be welded, riveted, and diffusion bonded with no particular problems. No effects of degradation of fabricated panels were observed after high-temperature exposure. Tensile strength of spot-welds showed a degradation with exposure time.

4. Strength of stainless steels after exposures up to 30 000 hours at 550° F (561° K) have shown no significant change except for AISI 301 steel.

5. Loss of creep strength in aluminum alloys limits the operating temperatures for longtime exposures.

6. Polyimide-resin—glass-fiber composite materials appear suitable for extended use in a Mach 2.7 supersonic transport. Although complete strength degradation occurs in 2000 hours at 600° F (589° K), no significant degradation has occurred after 4000 hours at 450° F (505° K) and a correlation plot indicates a service life estimate of 30 000 to 60 000 hours at 450° F (505° K).

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 17, 1967,
129-03-06-05-23.

APPENDIX

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, Paris, October 1960 (ref. 6). Conversion factors for the units used herein are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI Unit
Temperature . .	(^{o}F + 460)	5/9	degrees Kelvin (^{o}K)
Stress, Modulus	ksi = kips/in^2	6.895×10^6	newtons/meter^2 (N/m^2)
Pressure	torr	133.3	newtons/meter^2 (N/m^2)
Length	in.	0.0254	meters (m)
	ft	0.3048	meters (m)

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI Unit.

Prefixes to indicate multiple of units are as follows:

Prefix	Multiple
micro (μ)	10^{-6}
centi (c)	10^{-2}
kilo (k)	10^3
mega (M)	10^6

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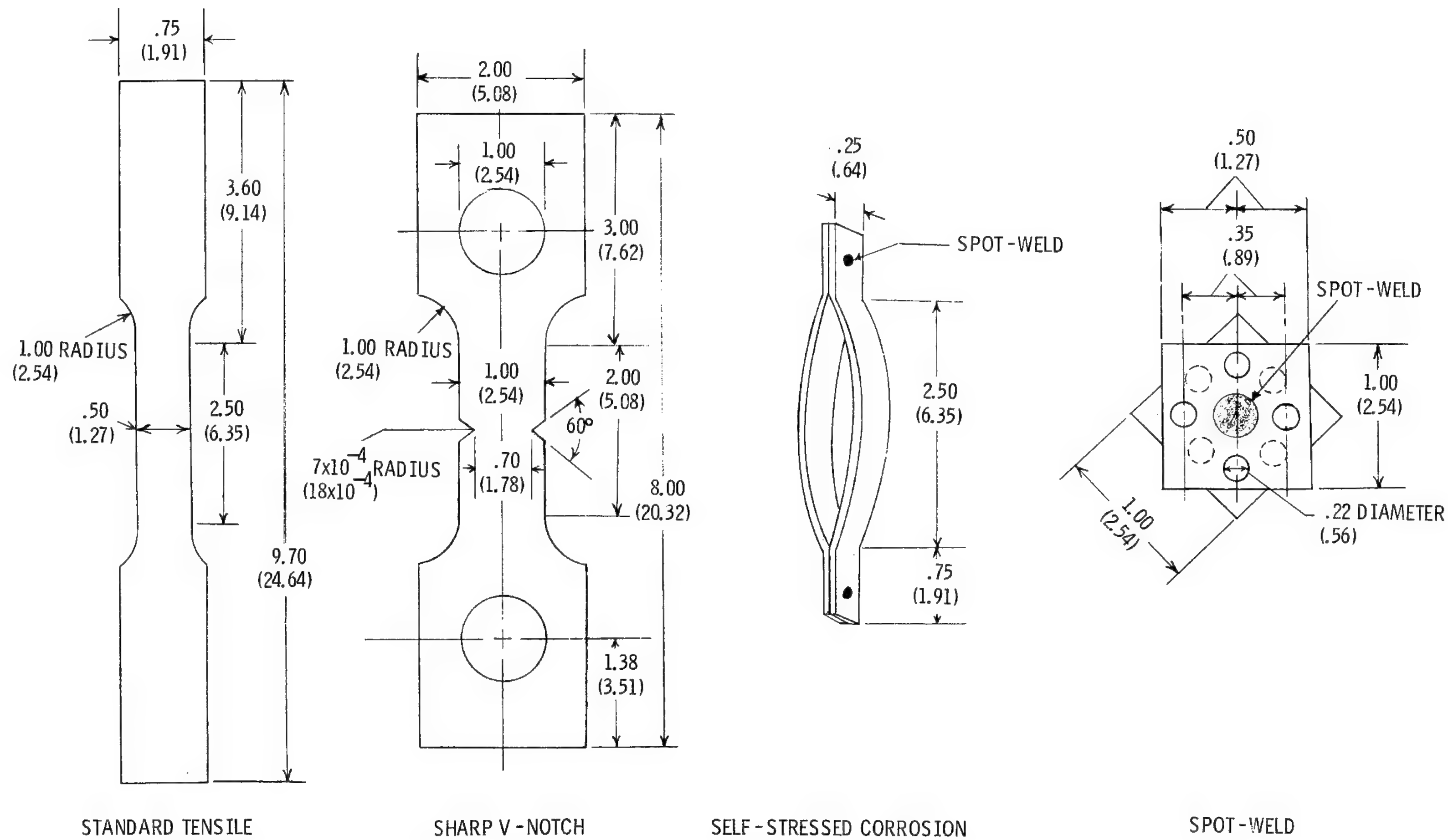
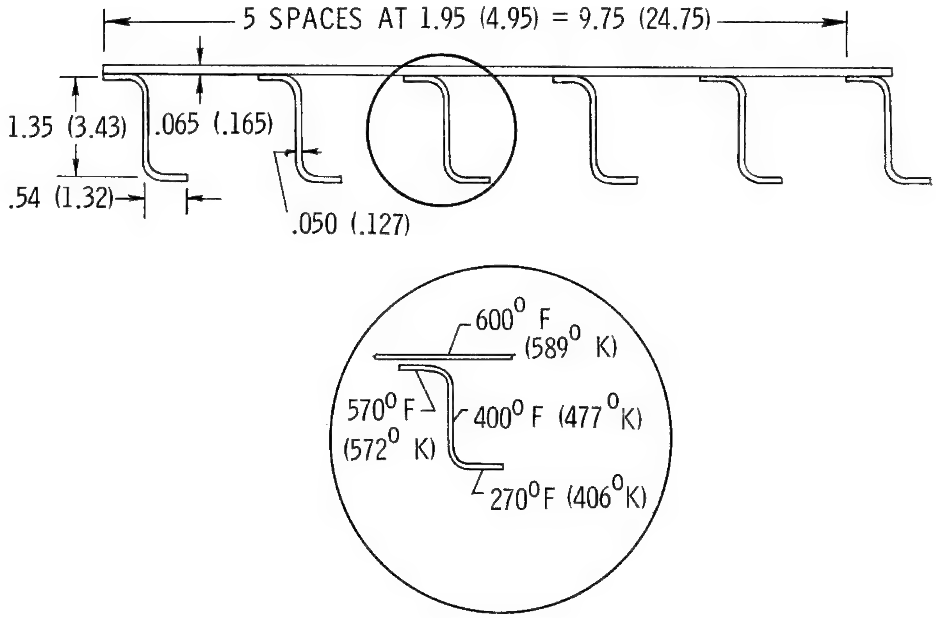
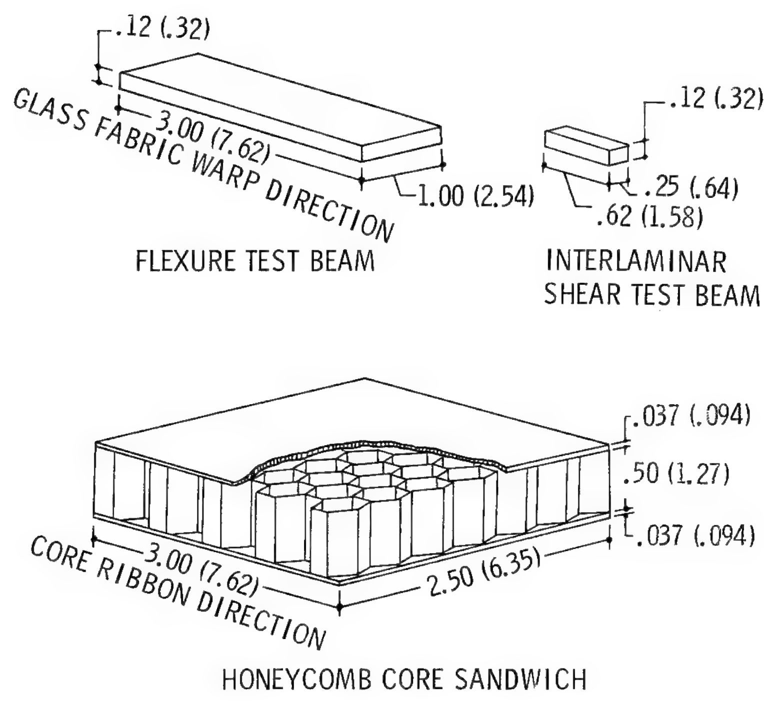


(a) Sheetmetal material test specimens.

Figure 1.- Test specimens. Dimensions are shown in inches and parenthetically in centimeters unless indicated otherwise.



(b) Skin-stringer panel design and average element temperatures for 600° F (589° K) tests.



(c) Polyimide-resin—glass-fiber composite material test specimens.

Figure 1.- Concluded.

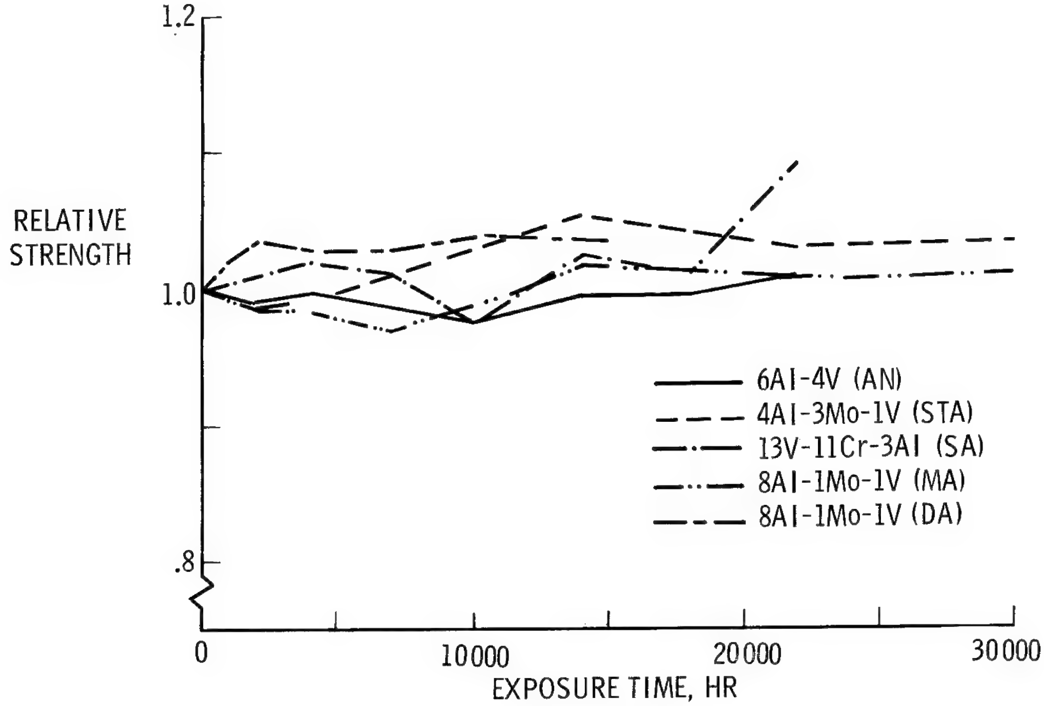


Figure 2.- Effect of exposure at 550° F (561° K) on room-temperature tensile strength of titanium-alloy sheet.

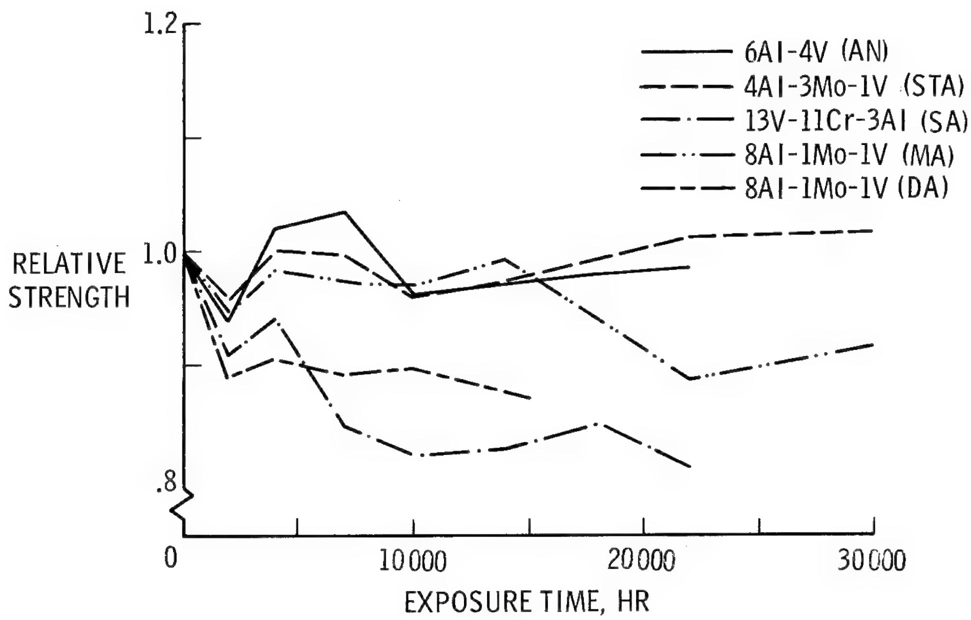


Figure 3.- Effect of exposure at 550° F (561° K) on room-temperature notch tensile strength of titanium-alloy sheet.

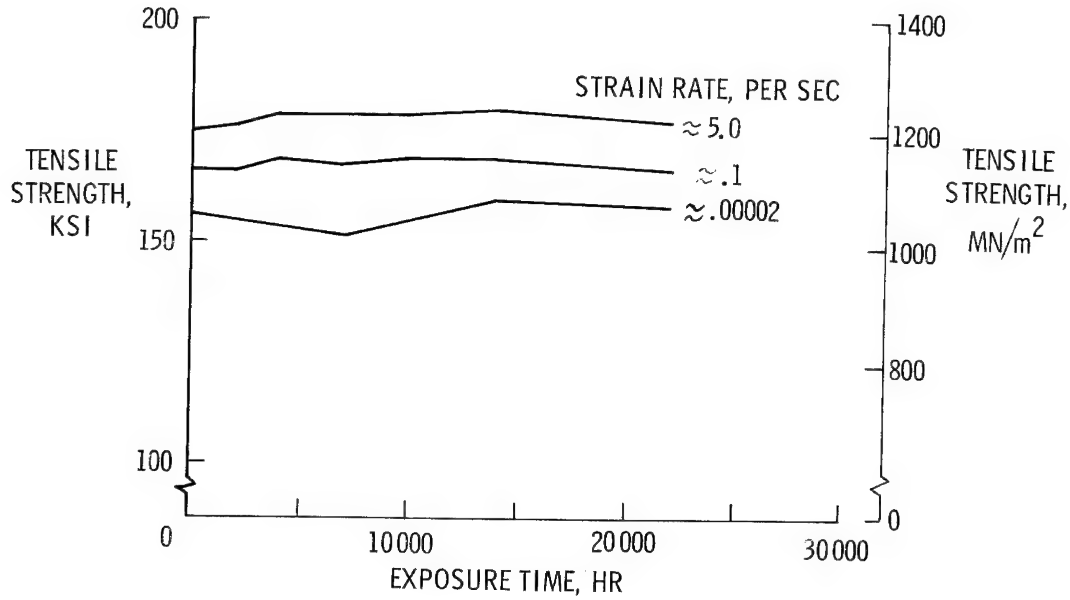


Figure 4.- Strain-rate sensitivity of room-temperature tensile strength of Ti-8Al-1Mo-1V (MA) alloy after exposures at 550° F (561° K).

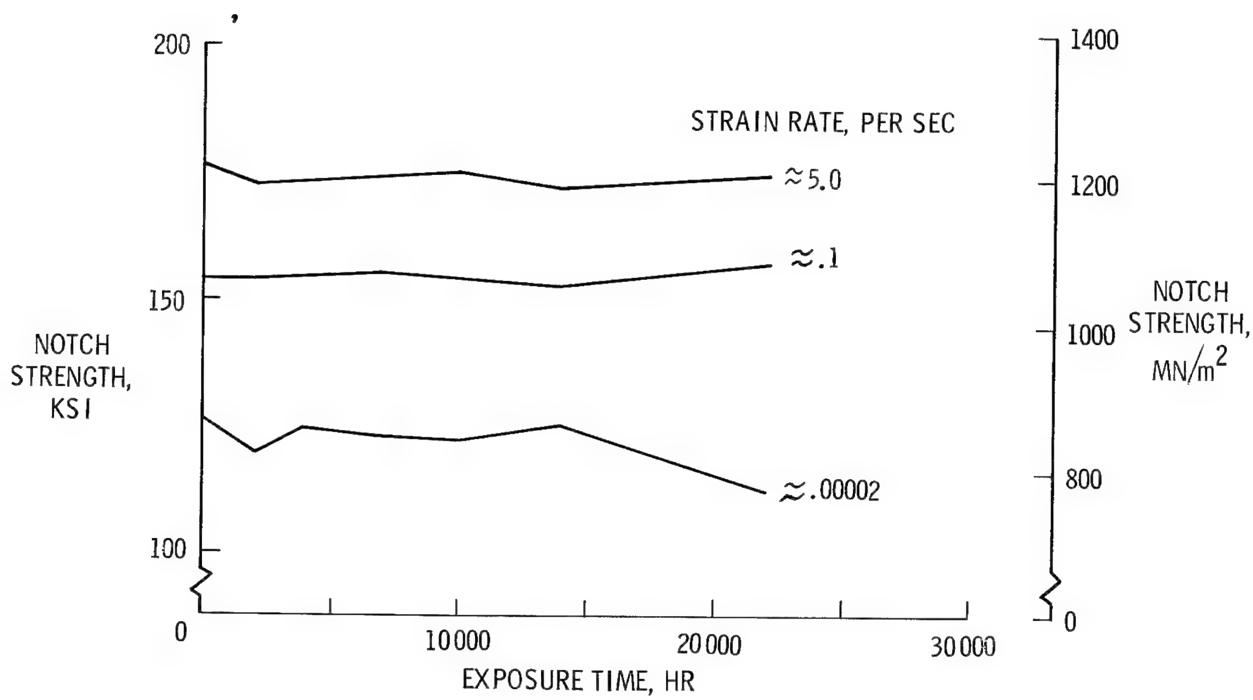


Figure 5.- Strain-rate sensitivity of room-temperature notch strength of Ti-8Al-1Mo-1V (MA) alloy after exposures at 550° F (561° K).

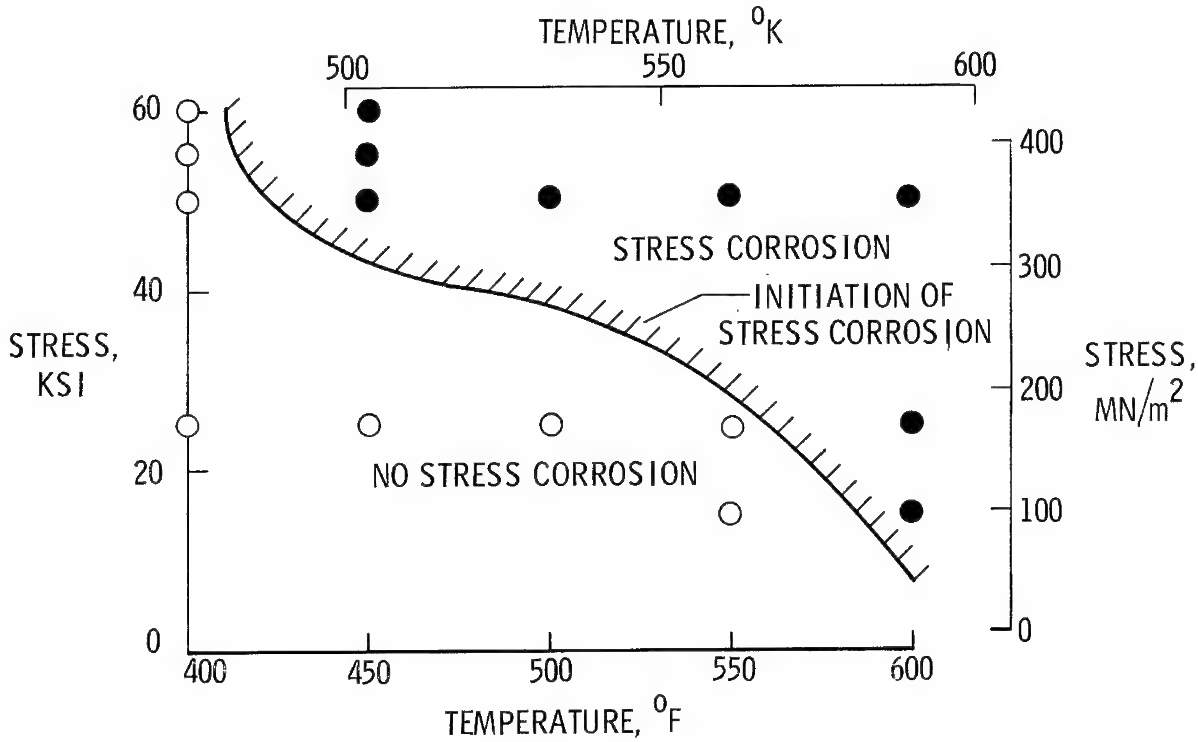


Figure 6.- 10 000-hour threshold for hot-salt stress corrosion of Ti-8Al-1Mo-1V (DA) alloy sheet.

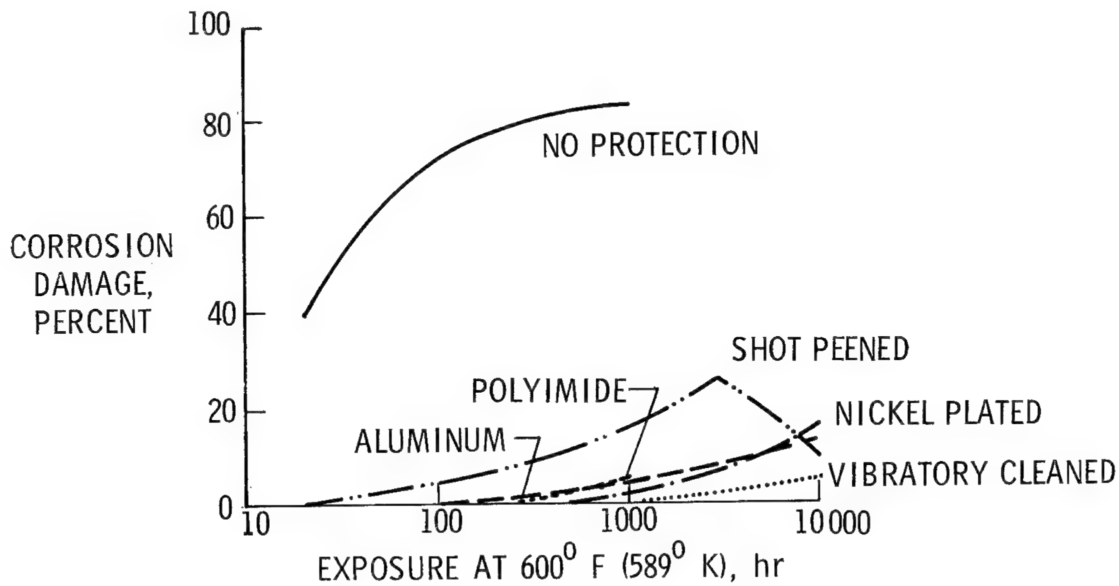


Figure 7.- Effect of various protective treatments on hot-salt stress corrosion of Ti-8Al-1Mo-1V (DA) alloy sheet.

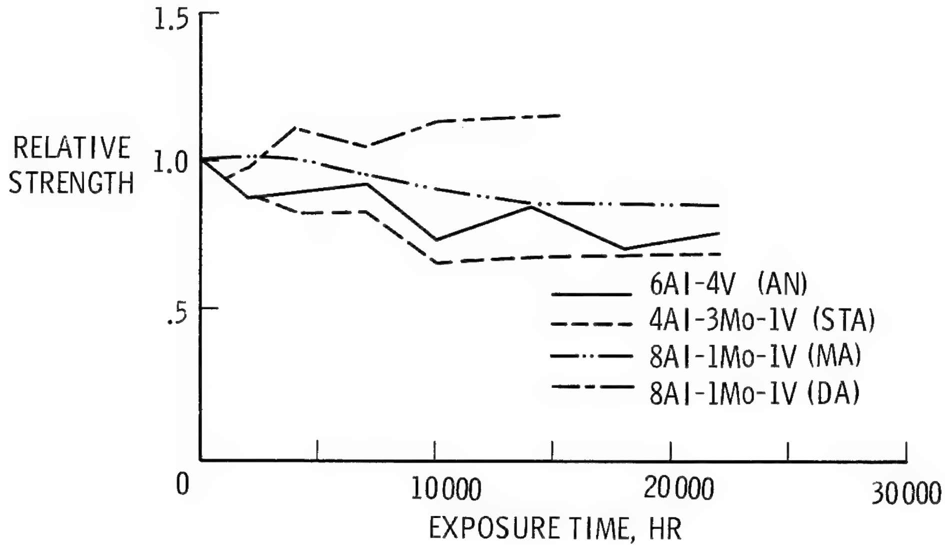


Figure 8.- Effect of exposure at 550° F (561° K) on room-temperature tensile spot-weld strength for titanium-alloy sheet.

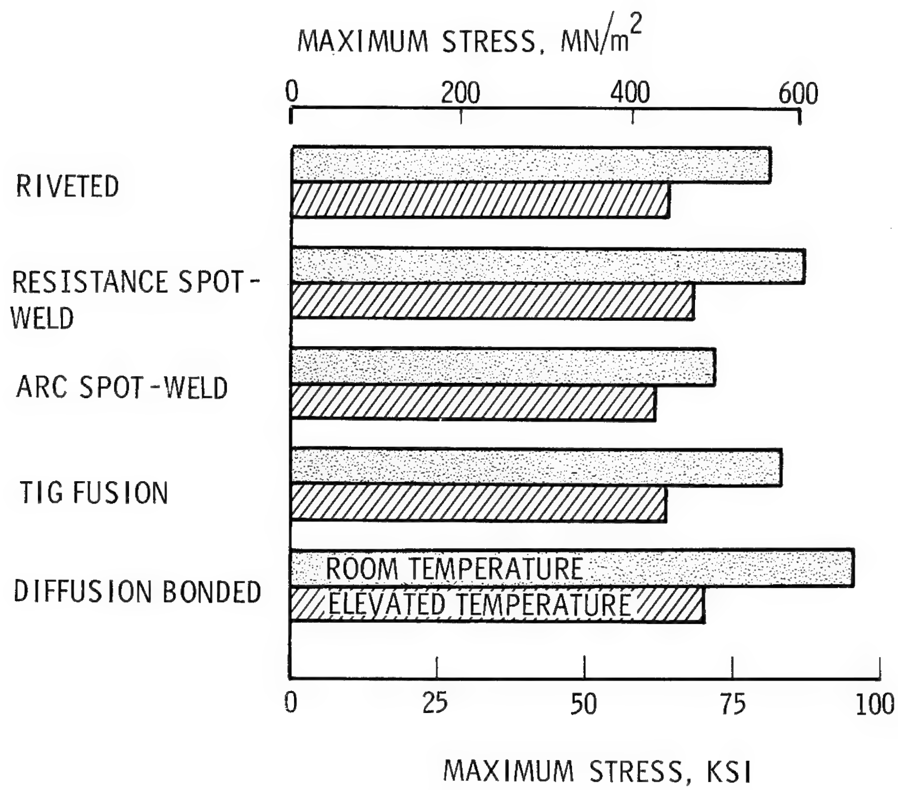


Figure 9.- Compressive strength of skin-stringer panels of Ti-8Al-1Mo-1V (DA) alloy at room temperature and 600° F (589° K).

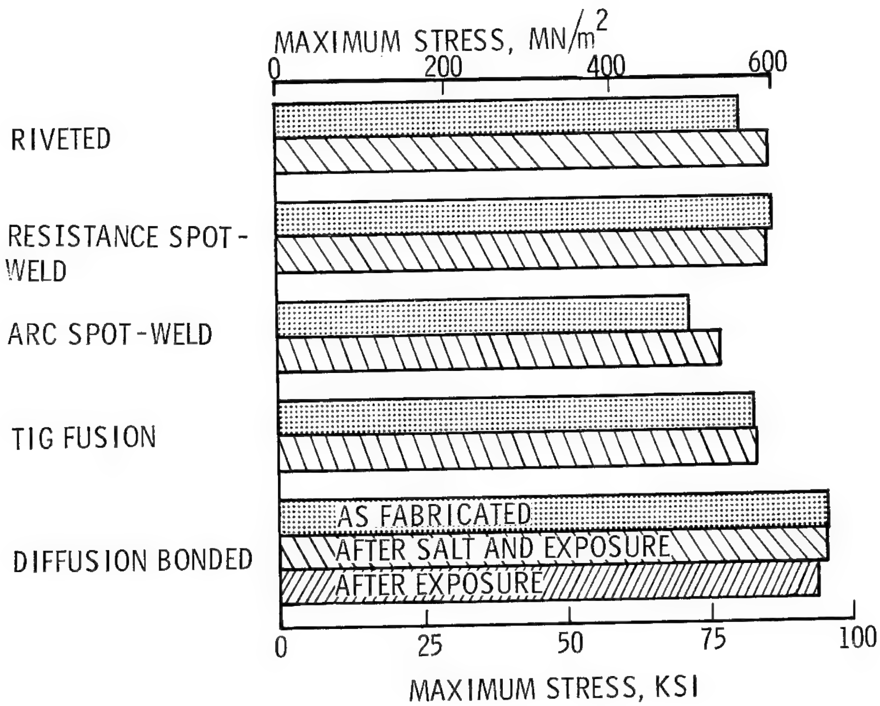


Figure 10.- Effect of 600° F (589° K) 1000-hour exposure on room-temperature compressive strength of skin-stringer panels.

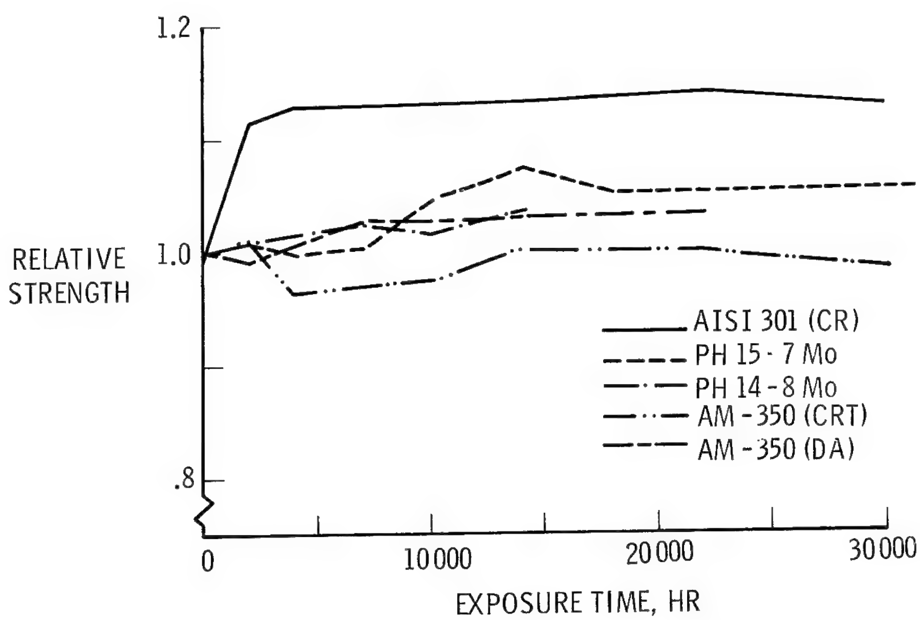


Figure 11.- Effect of unstressed exposure at 550° F (561° K) on room-temperature tensile strength of stainless-steel sheet.

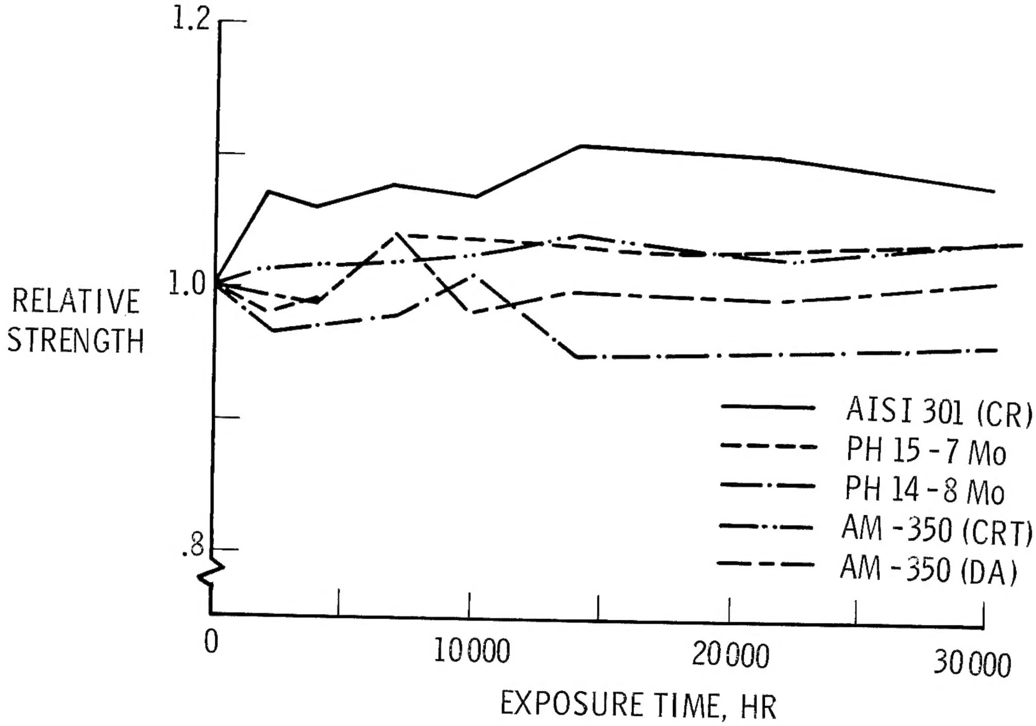


Figure 12.- Effect of unstressed exposure at 550° F (561° K) on room-temperature notch tensile strength of stainless-steel sheet.

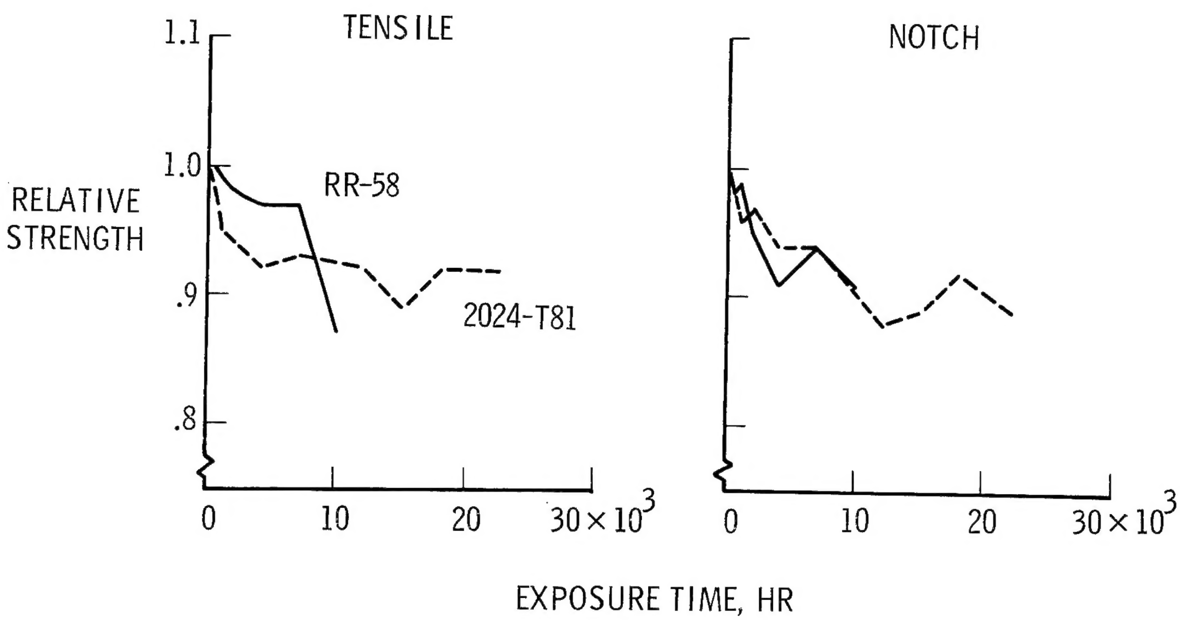


Figure 13.- Effect of unstressed exposure at 300° F (422° K) on room-temperature strength of aluminum-alloy sheet.

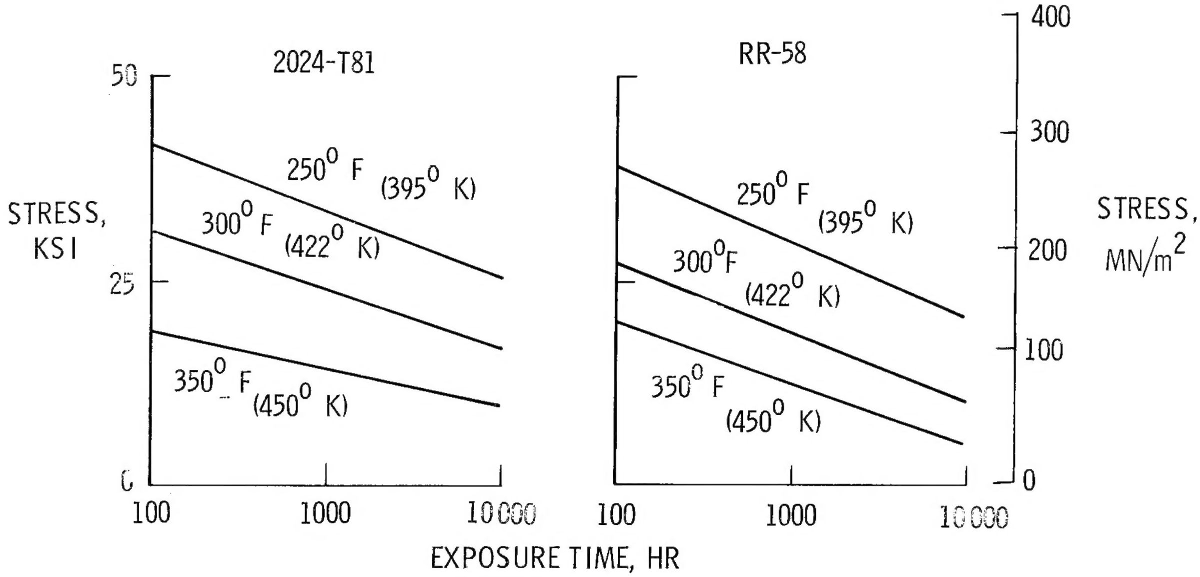


Figure 14.- Stress to produce 0.1-percent creep strain in aluminum-alloy sheet.

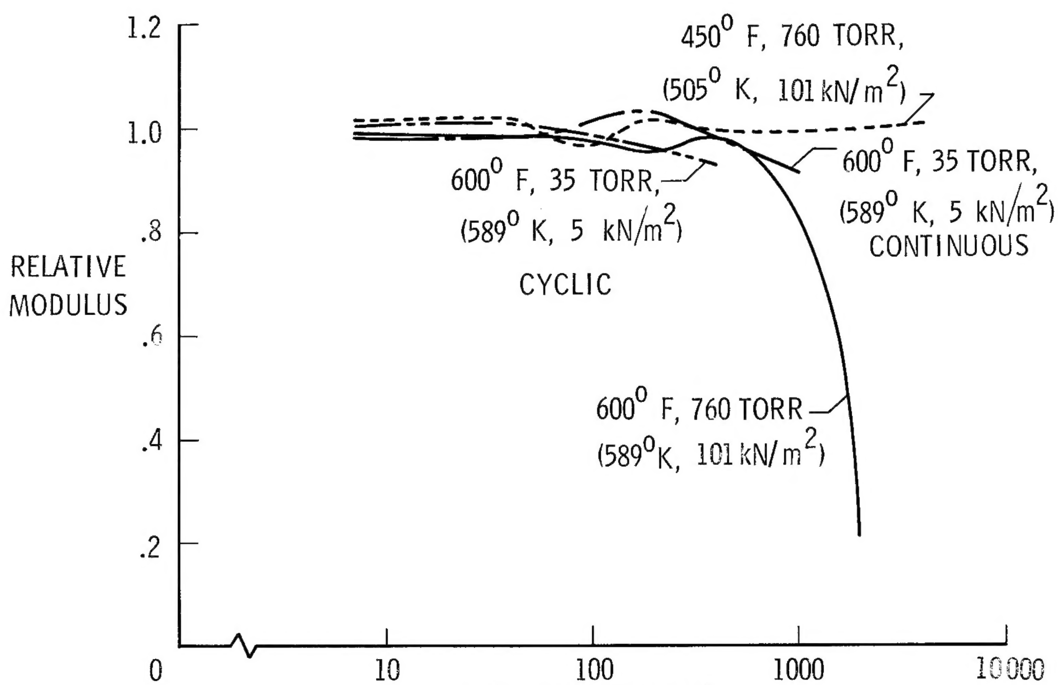


Figure 15.- Effect of exposure on room-temperature edgewise compressive stiffness of polyimide-resin—glass-fiber sandwiches.

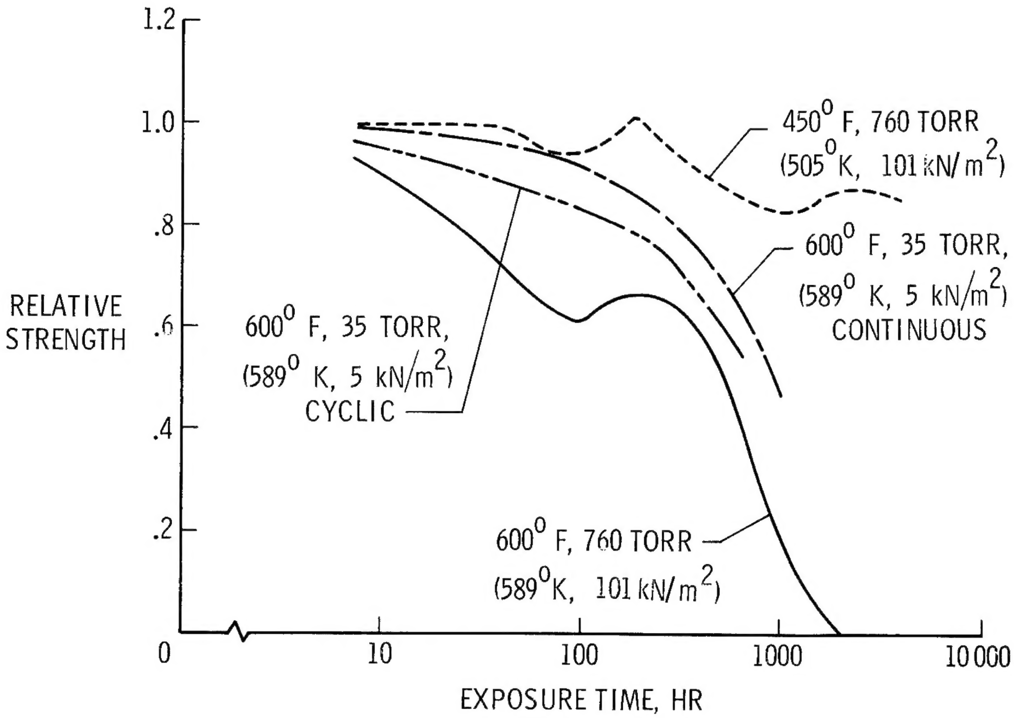


Figure 16.- Effect of exposure on room-temperature compressive strength of polyimide-resin—glass-fiber sandwiches.

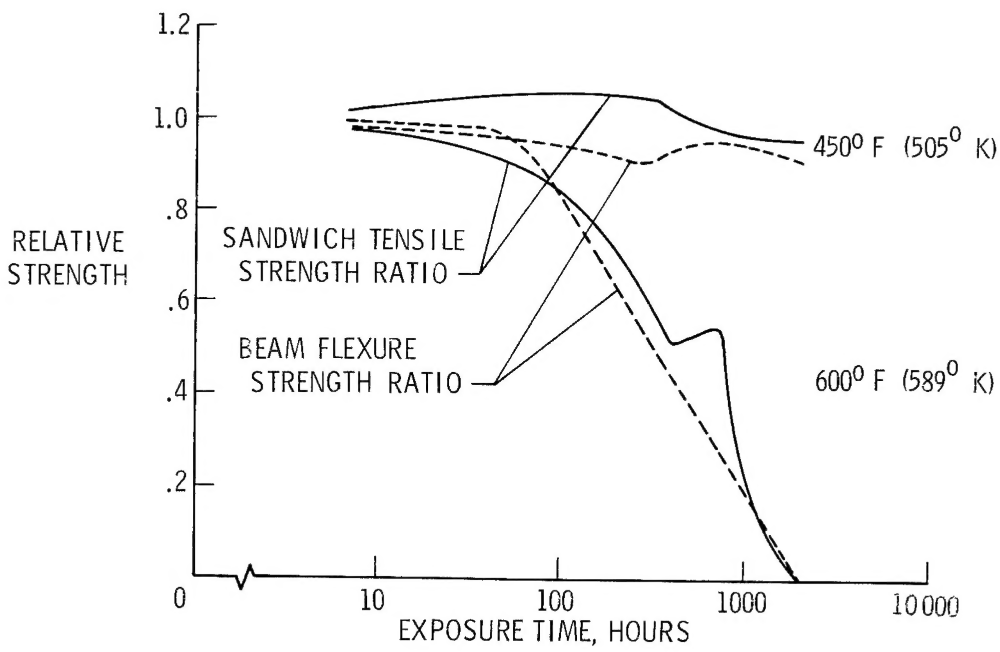


Figure 17.- Comparison of the effect of 760-torr (101 kN/m2) exposures on flatwise tensile strength ratio of sandwiches with flexure strength ratio of beams.

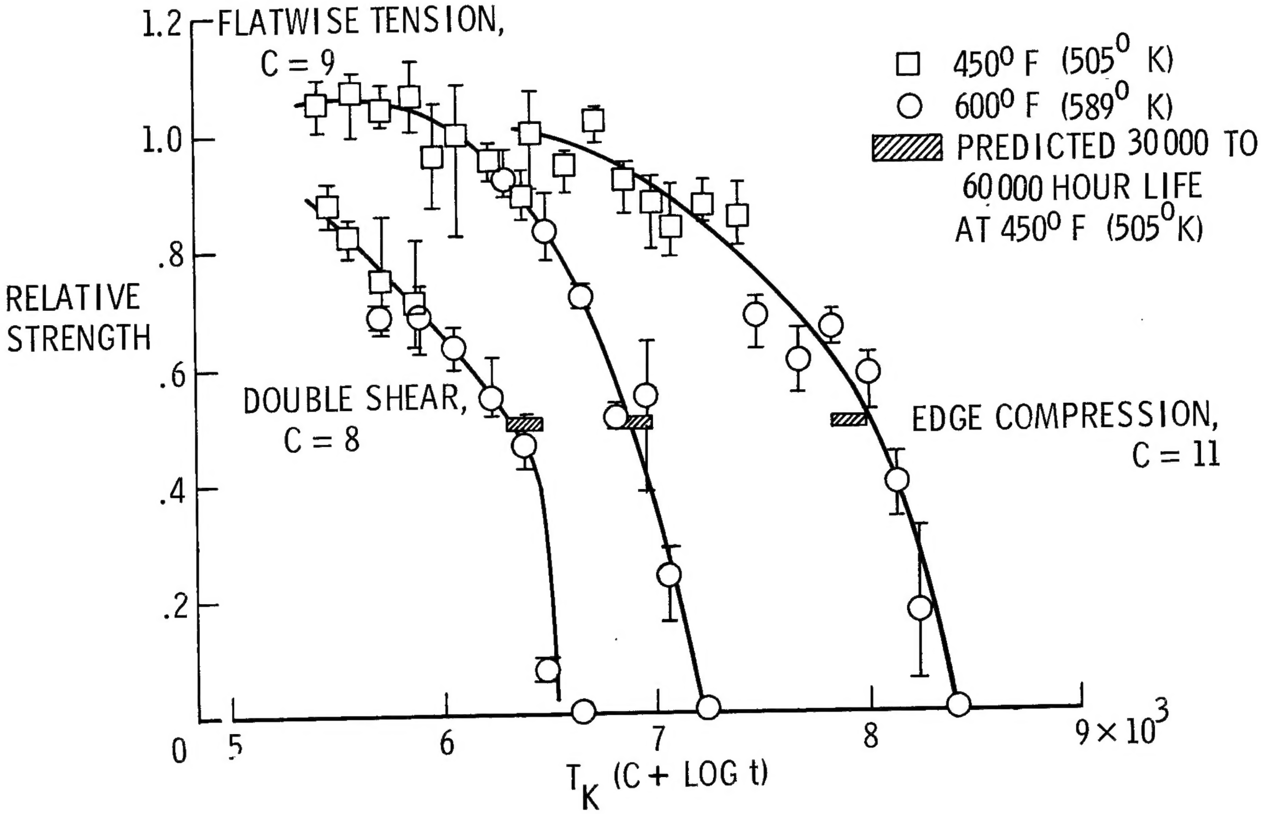


Figure 18.- Strength correlation of high-temperature exposure effects for polyimide-resin—glass-fiber sandwiches.

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